

A detailed illustration of the Europa Clipper spacecraft in orbit around the planet Europa. The spacecraft is shown from a three-quarter perspective, highlighting its large solar panel arrays and central body. Europa's surface is covered in a complex network of reddish-brown and white ice cracks. In the background, the massive, swirling clouds of Jupiter are visible against the blackness of space.

# EUROPA CLIPPER

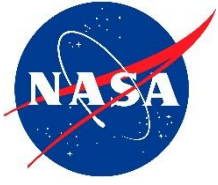
## Exploring Ocean World Habitability with the Europa Clipper Mission

Robert Pappalardo

*Europa Clipper Project Scientist, Jet Propulsion Laboratory, California Institute of Technology*  
and the Europa Clipper Science Team

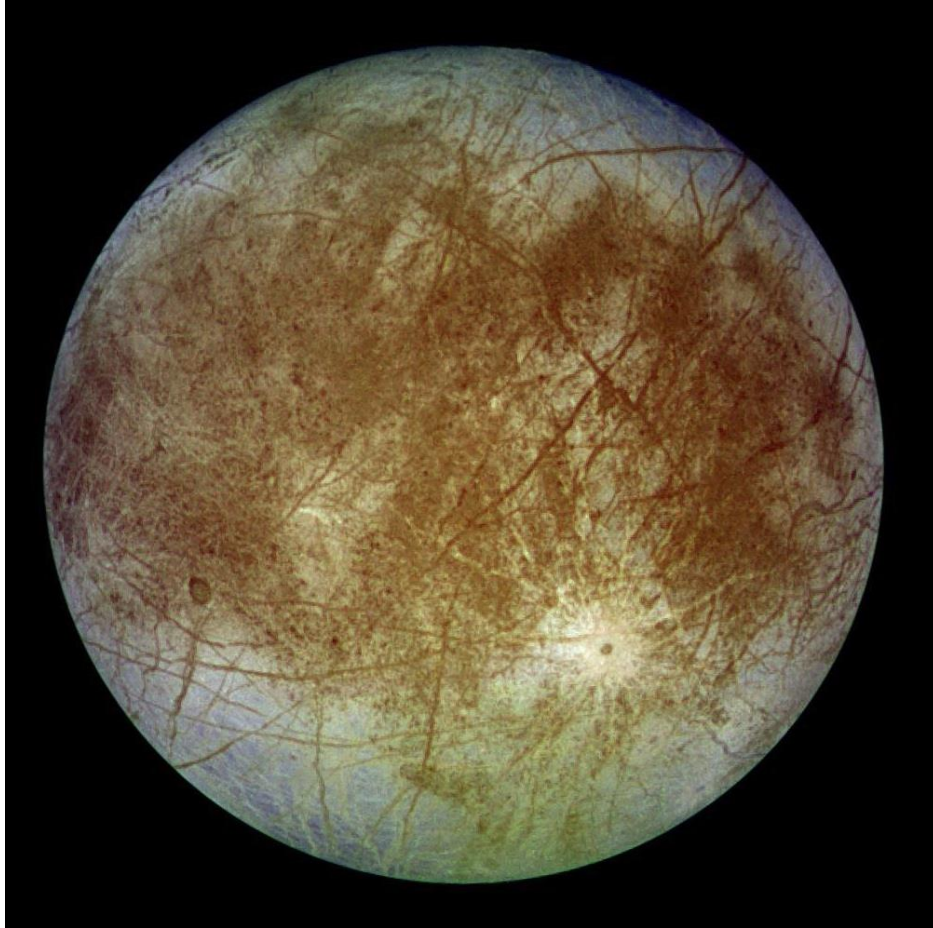
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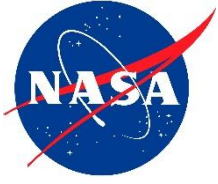


# Europa: Key to Icy World Habitability

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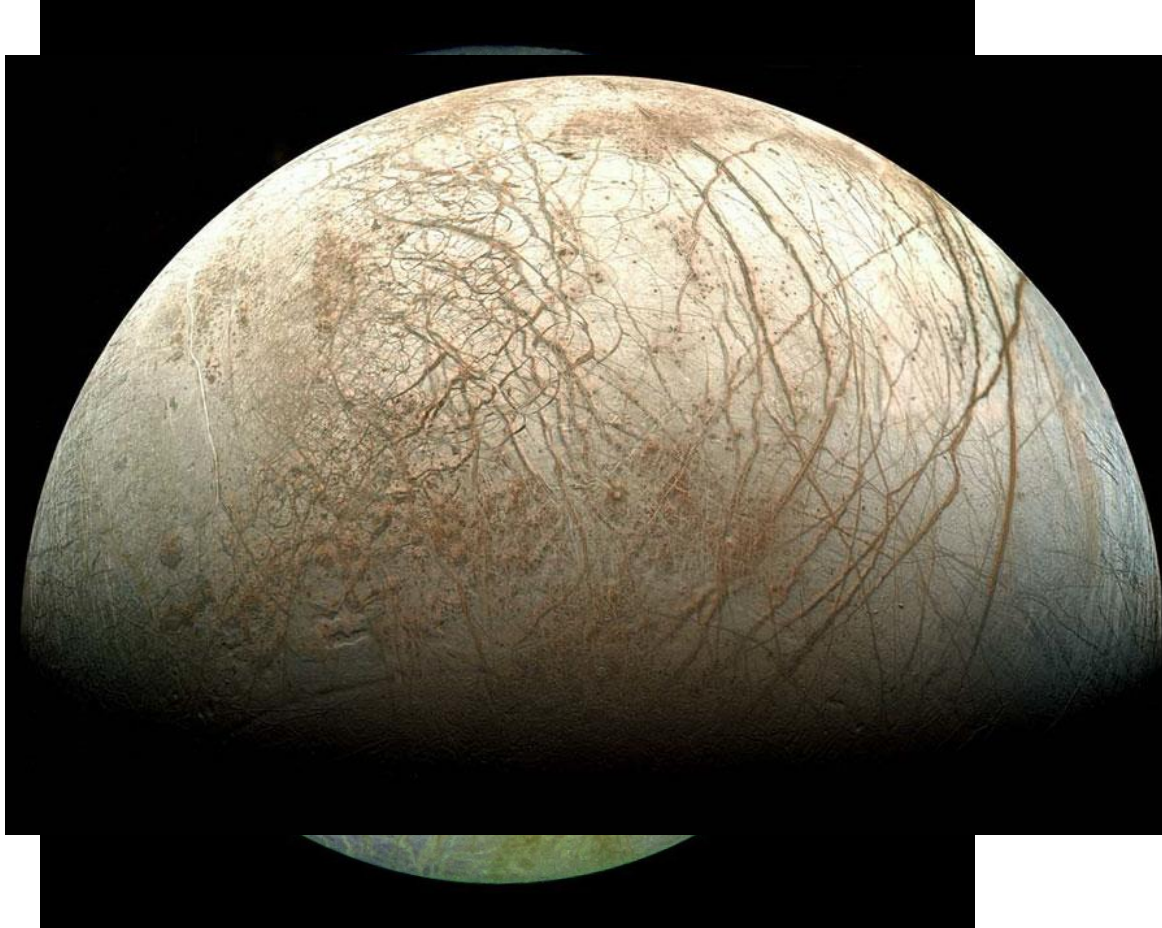


- A world of rock, ice, and water the size of Earth's moon

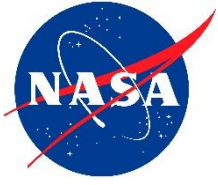


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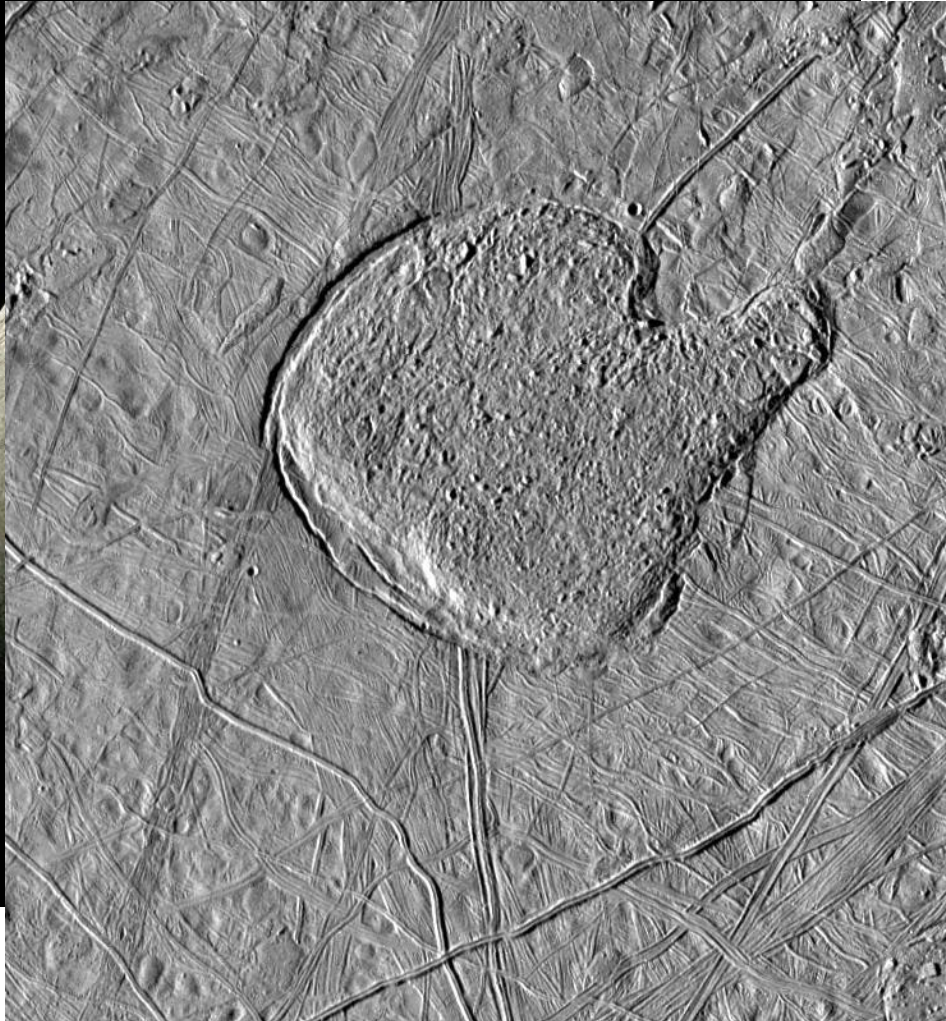
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- A world of rock, ice, and water the size of Earth's moon
- One of the youngest surfaces in the solar system

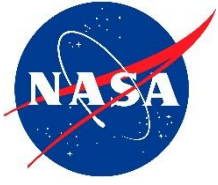


# Europa: Key to Icy World Habitability

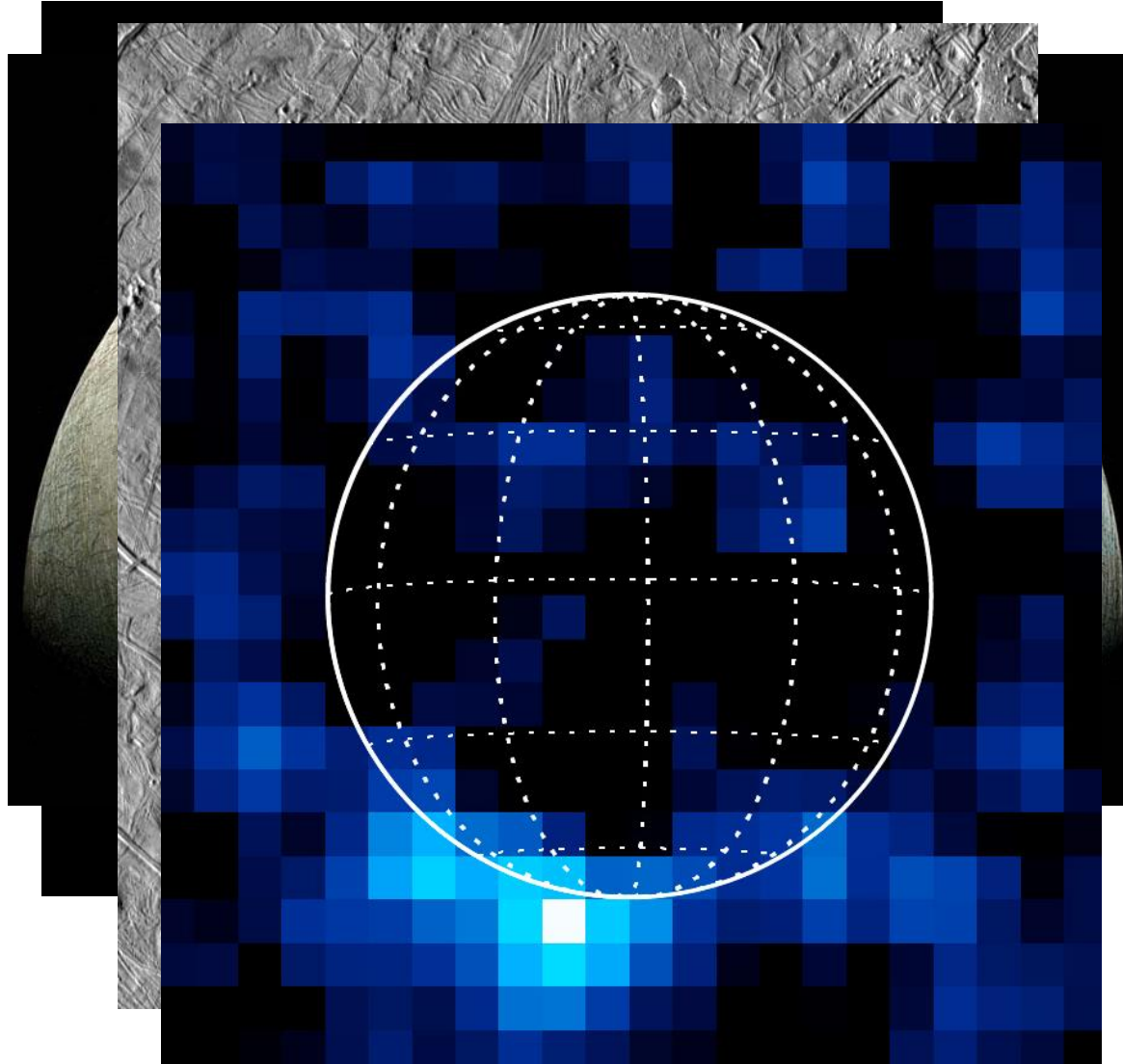


- A world of rock, ice, and water the size of Earth's moon
- One of the youngest surfaces in the solar system
- Plentiful cryovolcanism

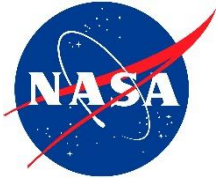




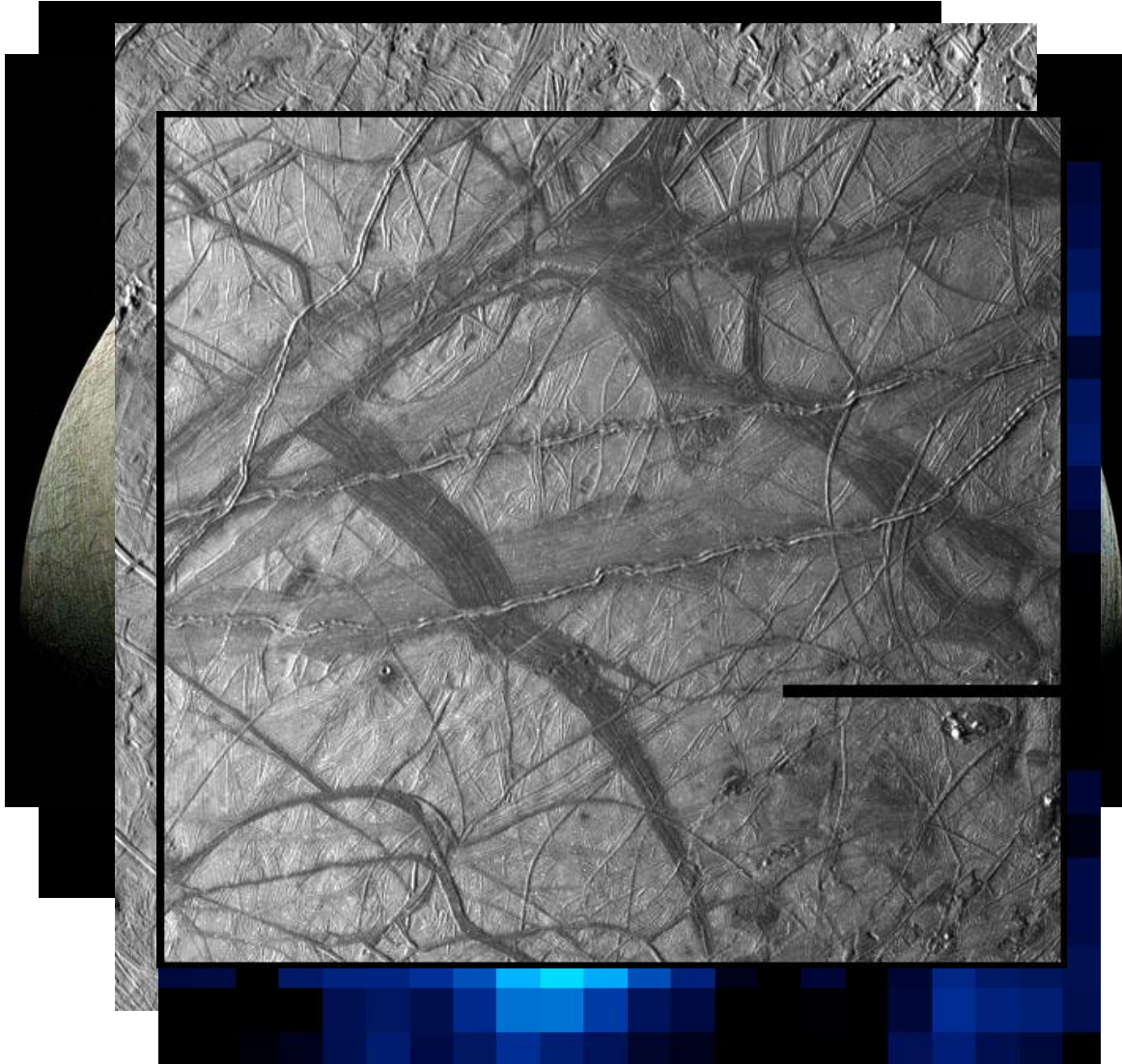
# Europa: Key to Icy World Habitability



- A world of rock, ice, and water the size of Earth's moon
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- Plentiful cryovolcanism
- Possible geysers and plumes

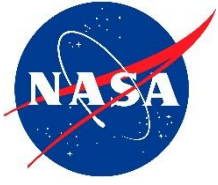


# Europa: Key to Icy World Habitability

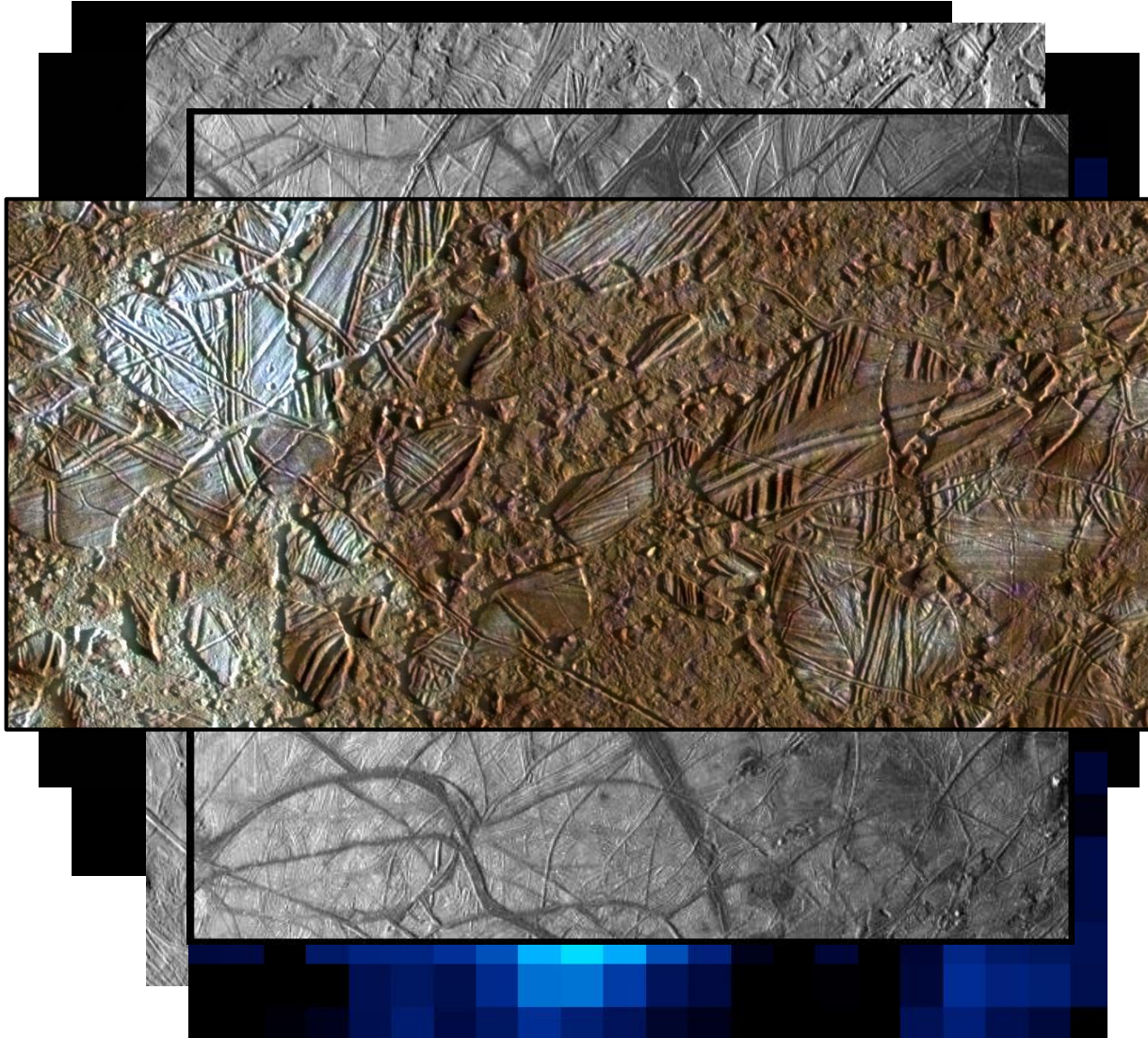


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- Possible geysers and plumes
- Earth-like tectonic activity

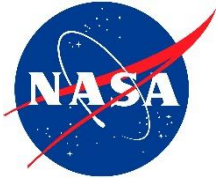




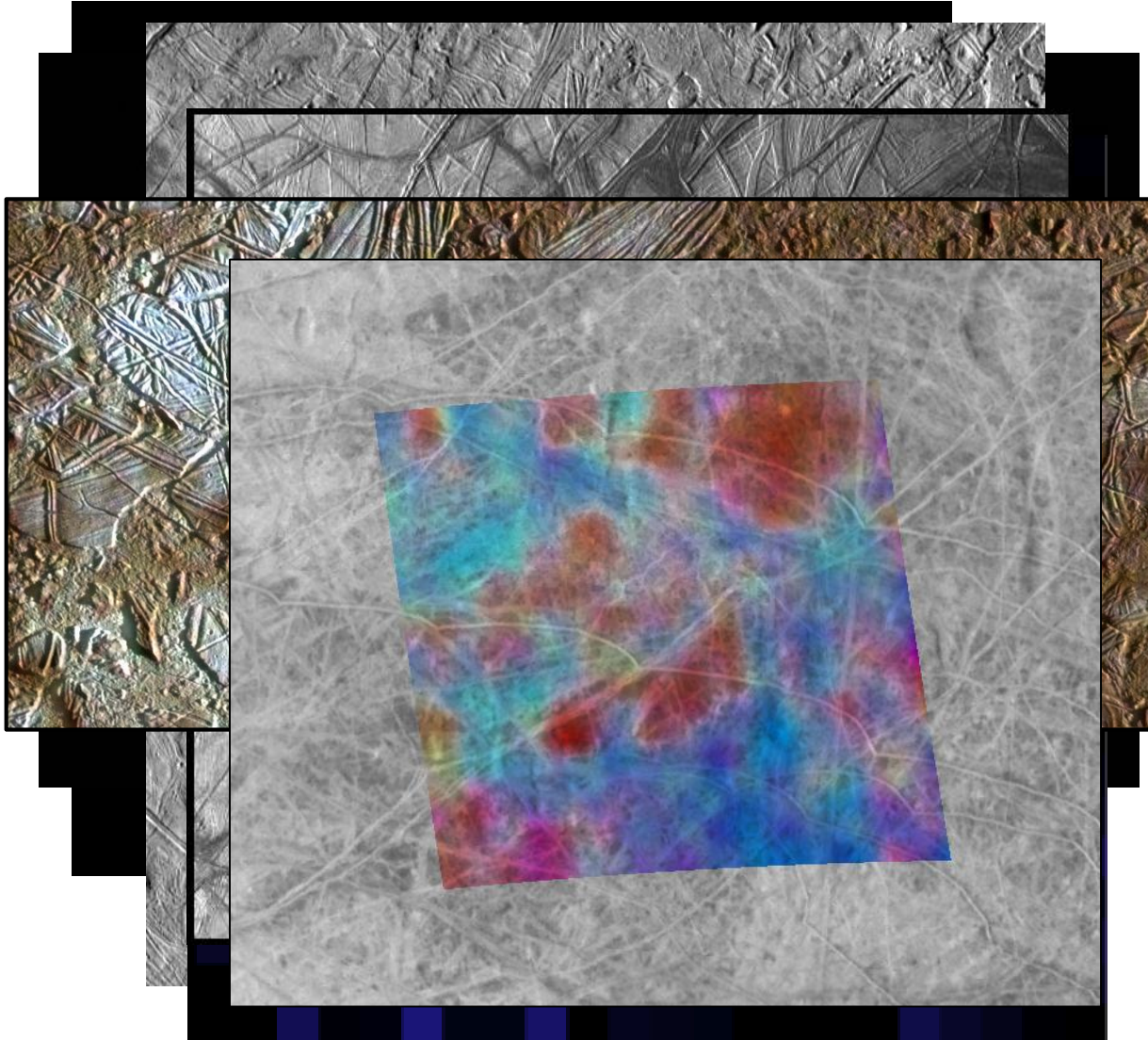
# Europa: Key to Icy World Habitability



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- Plentiful cryovolcanism
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- Widespread surface disruption

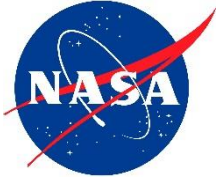


# Europa: Key to Icy World Habitability

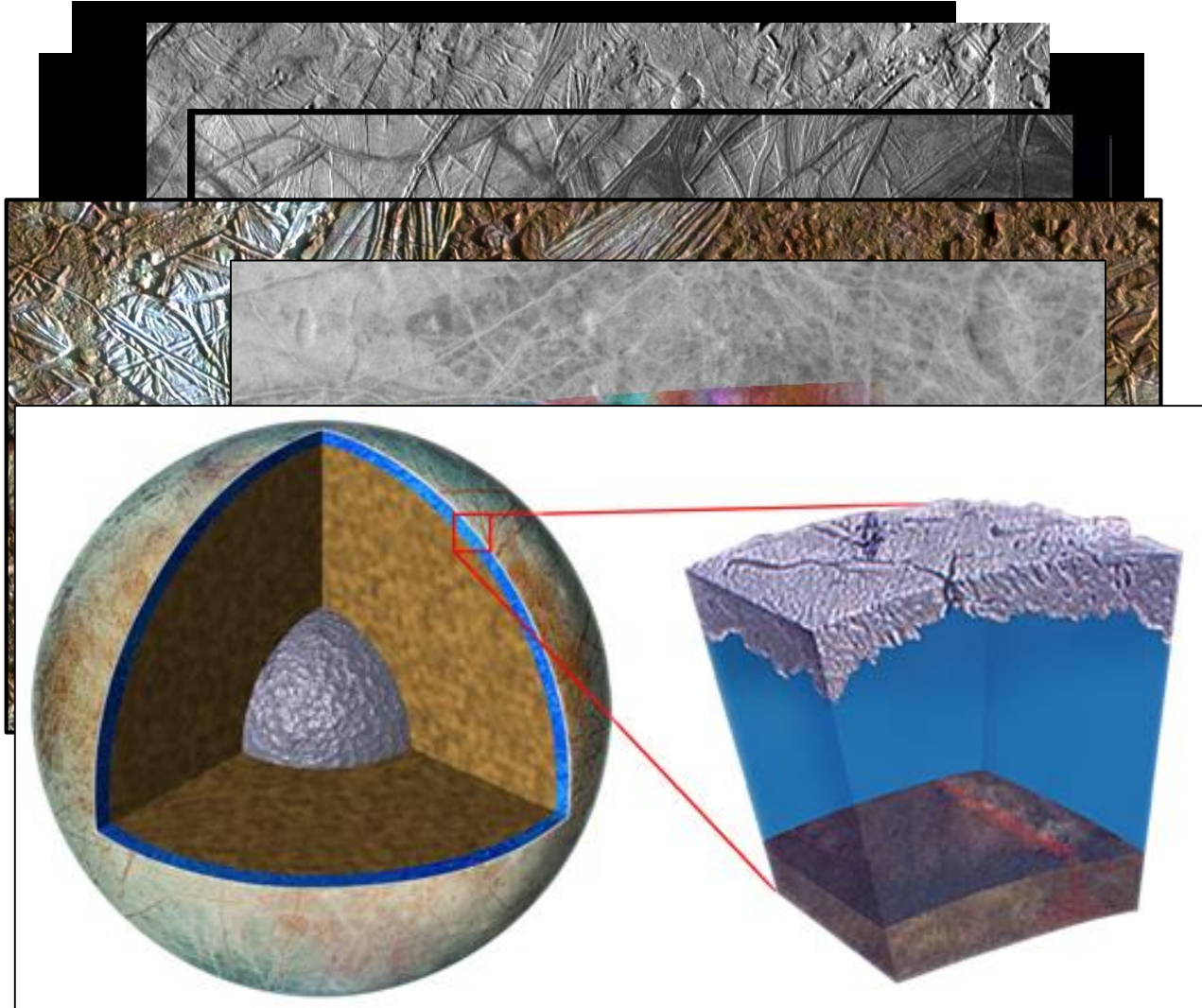


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# Europa: Key to Icy World Habitability



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- Surface chemistry of salts and acid
- Subsurface ocean: Possibly our Solar System's best chance for extant life beyond Earth



# Exploring Europa's Habitability: Ingredients for Life

## Water:

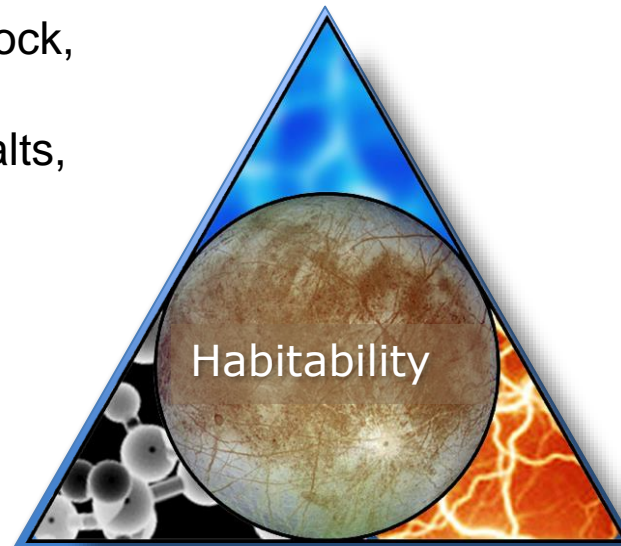
- Probable saltwater ocean, implied by surface geology and magnetic field
- Possible lakes within the ice shell, produced by local melting

## Chemistry:

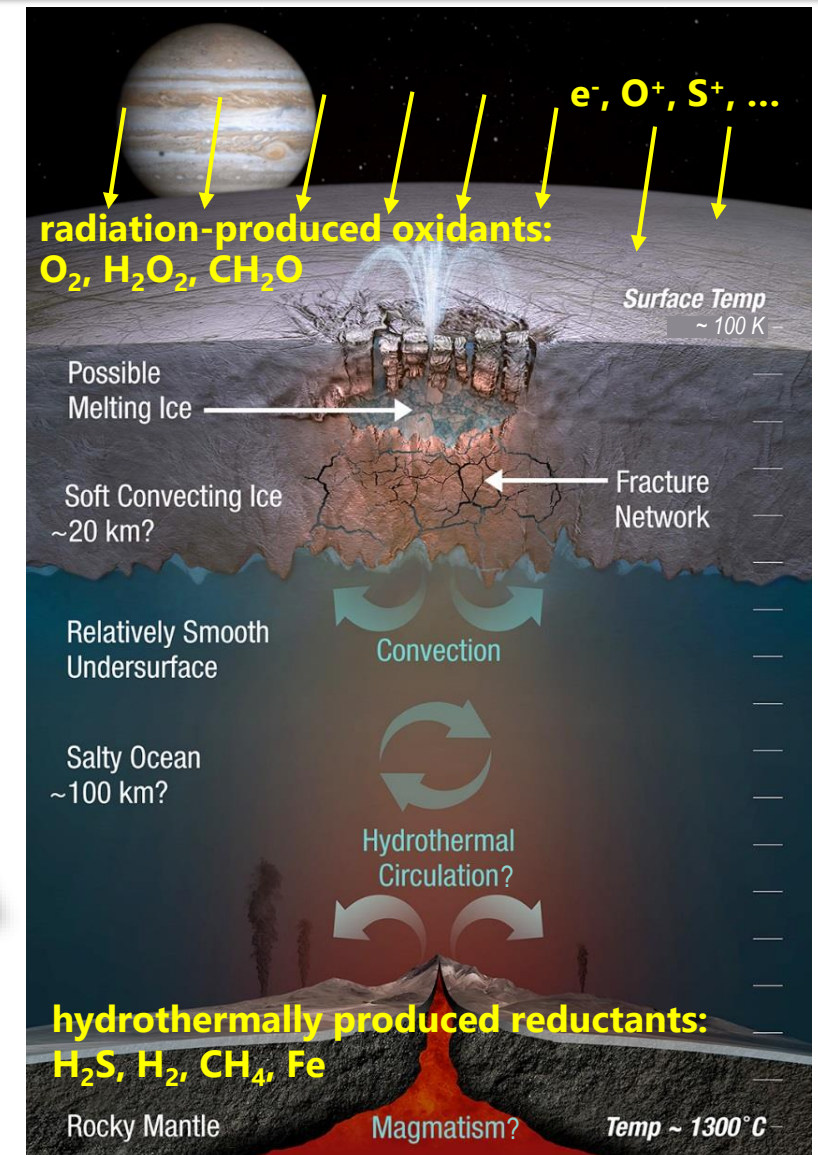
- Ocean in direct contact with mantle rock, promoting chemical leaching
- Dark red surface materials contain salts, probably from the ocean

## Energy:

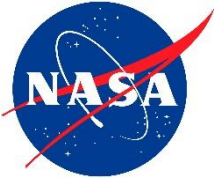
- Chemical energy might sustain life
- Surface irradiation creates oxidants
- Mantle rock-water reactions could create reductants (hydrothermal or serpentinization)



The Europa Clipper Mission will test key habitability hypotheses

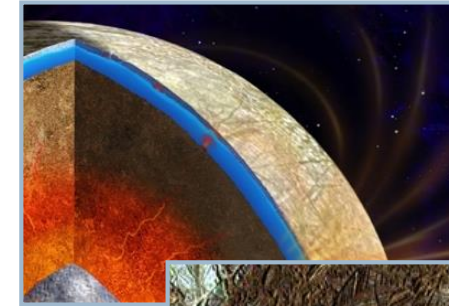






# Europa Clipper Science Overview

- *Mission Goal:* **Explore Europa to investigate its habitability**
- *Objectives:*
  - **Ice Shell & Ocean:** Characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange
  - **Composition:** Understand the habitability of Europa's ocean through composition and chemistry
  - **Geology:** Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities\*

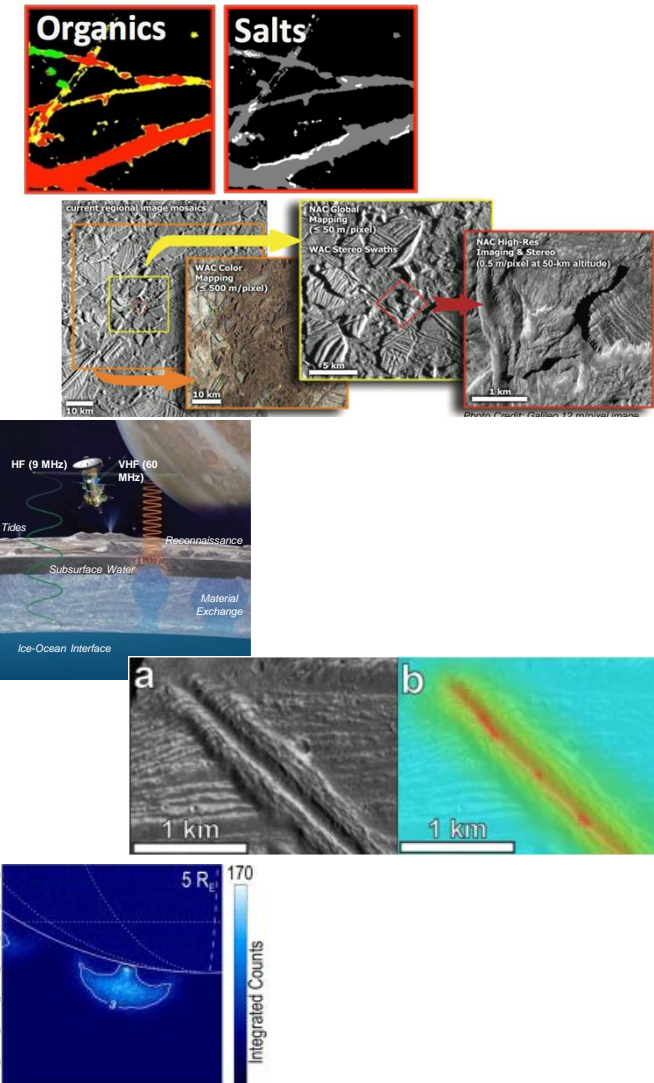


\* "Reconnaissance" is folded into the Geology objective.

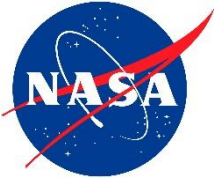


# Europa Clipper Remote Sensing Investigations

- **Mapping Imaging Spectrometer for Europa (MISE)** – PI Dr. Diana Blaney, JPL
  - Probe the composition of Europa, identifying and mapping the distributions of organics, salts, acid hydrates, water ice phases, and other materials to determine the habitability of Europa's ocean.
- **Europa Imaging System (EIS)** – PI Dr. Elizabeth Turtle, APL
  - Wide and narrow angle cameras to map most of Europa at better than 100 m resolution, and to provide images of areas of Europa's surface at up to 100 times higher resolution.
- **Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)** – PI Dr. Donald Blankenship, University of Texas, Austin
  - Characterize and sound Europa's icy crust from the near-surface to the ocean, revealing the hidden structure of Europa's ice shell and potential water within.
- **Europa Thermal Emission Imaging System (E-THEMIS)** – PI Dr. Philip Christensen, Arizona State University, Tempe
  - Provide high spatial resolution, multi-spectral thermal imaging of Europa to help detect active sites, such as potential vents erupting plumes of water into space.
- **Ultraviolet Spectrograph/Europa (UVS)** – PI Dr. Kurt Retherford, SwRI, San Antonio
  - Detect the likely presence of water plumes erupting from Europa's surface, including small plumes, and to provide valuable data about the composition and dynamics of Europa's rarefied atmosphere.

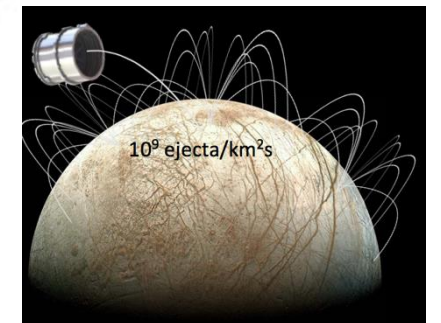
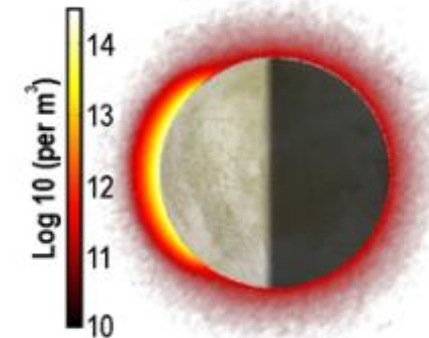
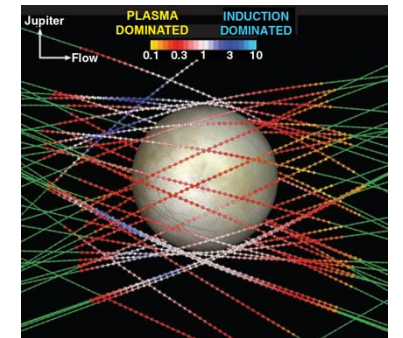
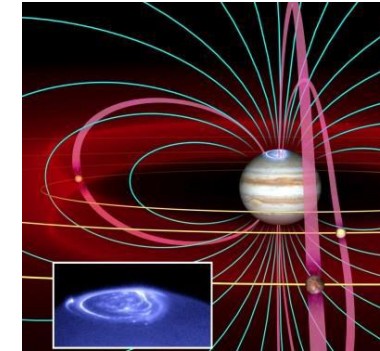


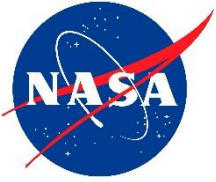




# Europa Clipper *In Situ* Investigations

- **Interior Characterization of Europa using Magnetometry (ICEMAG)** – PI Dr. Carol Raymond, JPL
  - Magnetometer to measure the magnetic field near Europa and infer the location, thickness and salinity of Europa's subsurface ocean using multi-frequency electromagnetic sounding.
- **Plasma Instrument for Magnetic Sounding (PIMS)** – PI Dr. Joseph Westlake, APL, Laurel, Maryland
  - In conjunction with a magnetometer, is key to determining Europa's ice shell thickness, ocean depth, and salinity by correcting the magnetic induction signal for plasma currents around Europa.
- **MAss SPectrometer for Planetary EXploration/Europa (MASPEX)** – PI Dr. Jack (Hunter) Waite, SwRI, San Antonio
  - To determine the composition of the surface and subsurface ocean by measuring Europa's extremely tenuous atmosphere and any surface material ejected into space.
- **SURface Dust Mass Analyzer (SUDA)** – PI Dr. Sascha Kempf, University of Colorado, Boulder
  - To measure the composition of small, solid particles ejected from Europa, providing the opportunity to directly sample the surface and potential plumes on low-altitude flybys.





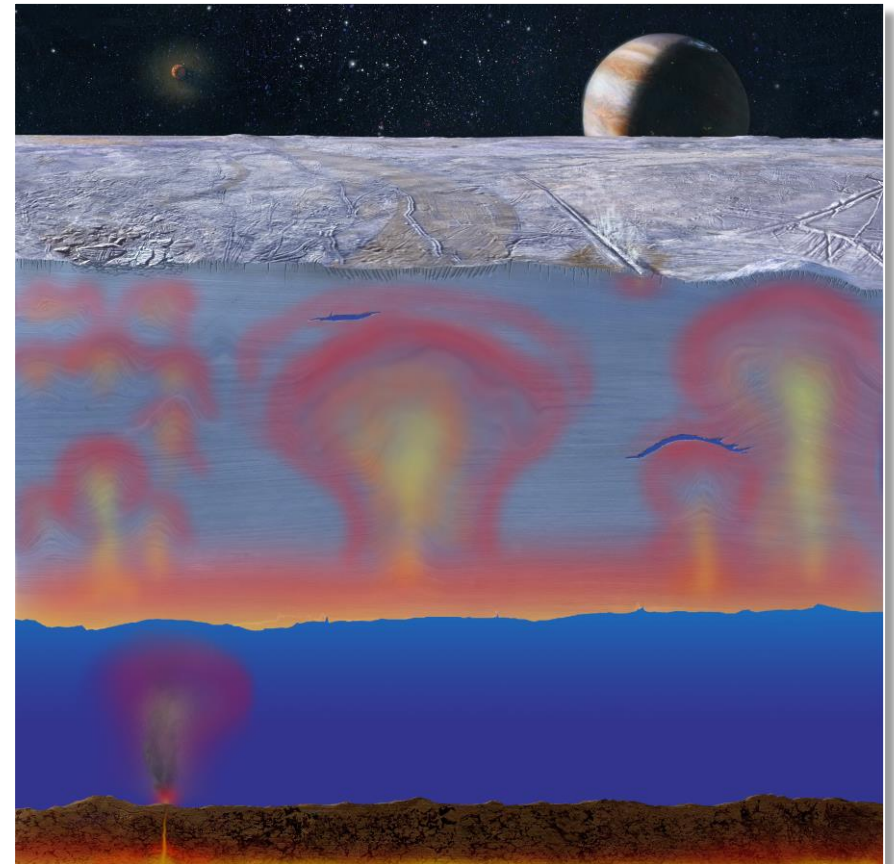
# Europa Clipper Science Objectives (1/3): *Ice Shell & Ocean*

- ***Ice Shell & Ocean Objective:***

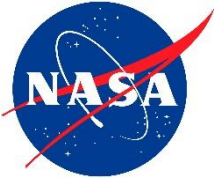
Characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange

- ***Ice Shell & Ocean Investigations:***

- Characterize the distribution of any shallow subsurface water and the structure of the icy shell [[EIS](#), [REASON](#)]
- Determine ocean salinity and thickness [[ICEMAG](#), [MISE](#), [PIMS](#), [SUDA](#)]
- Constrain the regional and global thickness, heat-flow, and dynamics of the ice shell [[E-THEMIS](#), [EIS](#), [Gravity](#), [ICEMAG](#), [PIMS](#), [REASON](#)]
- Investigate processes governing material exchange among the ocean, ice shell, surface, and atmosphere [[EIS](#), [ICEMAG](#), [MASPEX](#), [MISE](#), [REASON](#), [SUDA](#)]







# Europa Clipper Science Objectives (2/3): *Composition*

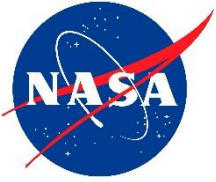
- ***Composition Objective:***

Understand the habitability of Europa's ocean through composition and chemistry

- ***Composition Investigations:***

- Characterize the composition and chemistry of endogenic materials on the surface and in the atmosphere, including potential plumes  
*[EIS, Europa-UVS, ICEMAG, MASPEX, MISE, PIMS, REASON, SUDA]*
- Determine the role of the radiation and plasma environment in creating and processing the atmosphere and surface materials  
*[EIS, Europa-UVS, MASPEX, MISE, PIMS, Radiation, REASON, SUDA]*
- Characterize the chemical and compositional pathways in the ocean  
*[EIS, ICEMAG, MASPEX, MISE, SUDA]*





# Europa Clipper Science Objectives (3/3): *Geology*

- ***Geology Objective:***

Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities

- ***Geology Investigations:***

- Determine sites of most recent geological activity, including potential plumes, and characterize localities of high science interest and potential future landing sites

*[E-THEMIS, EIS, Europa-UVS, MASPEX, MISE, PIMS, Radiation, REASON, SUDA]*

- Determine the formation and three-dimensional characteristics of magmatic, tectonic, and impact landforms

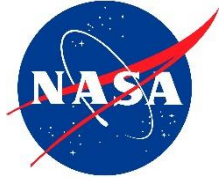
*[EIS, REASON]*

- Investigate processes of erosion and deposition and their effects on the physical properties of the surface

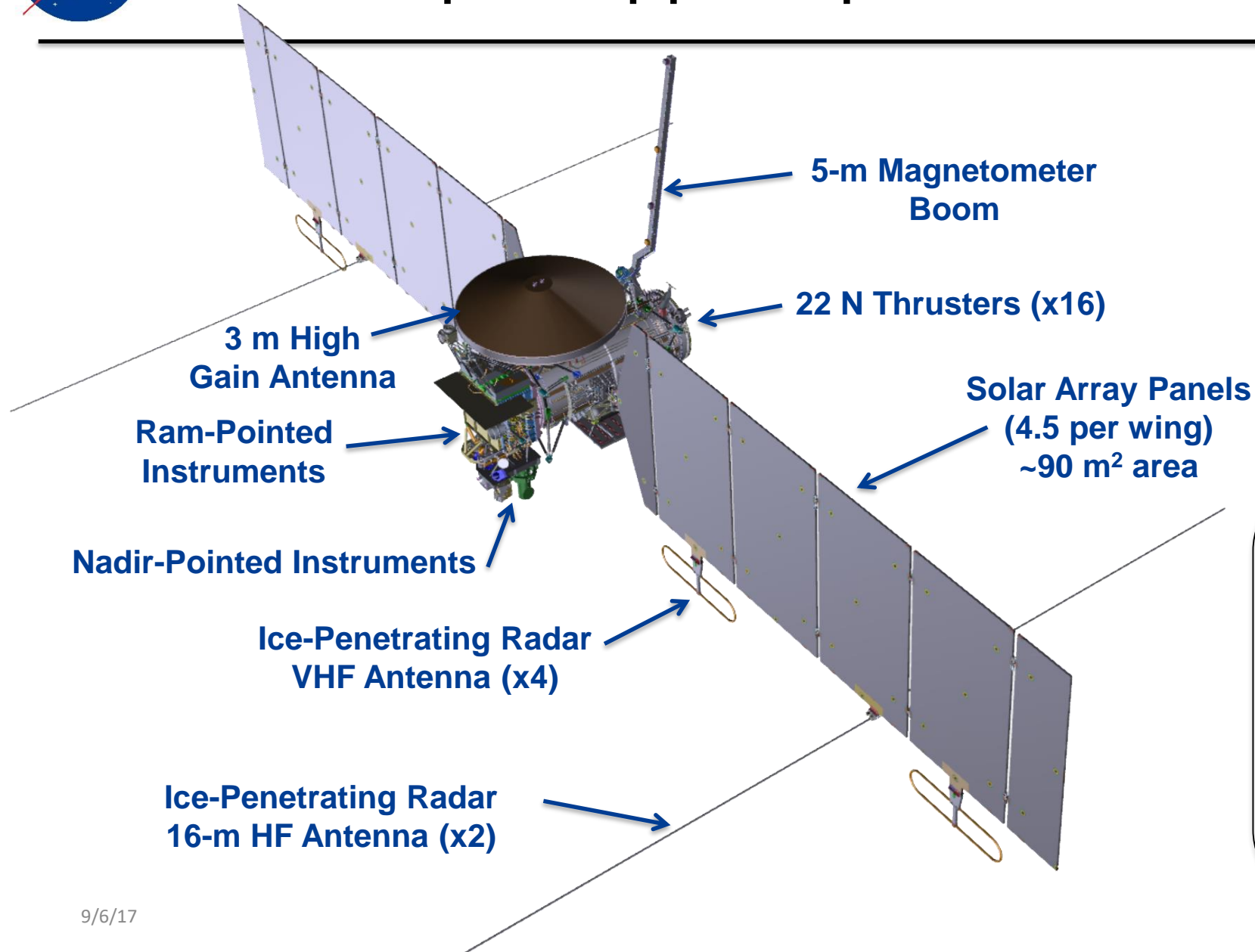
*[E-THEMIS, EIS, Europa-UVS, PIMS, Radiation, REASON, SUDA]*



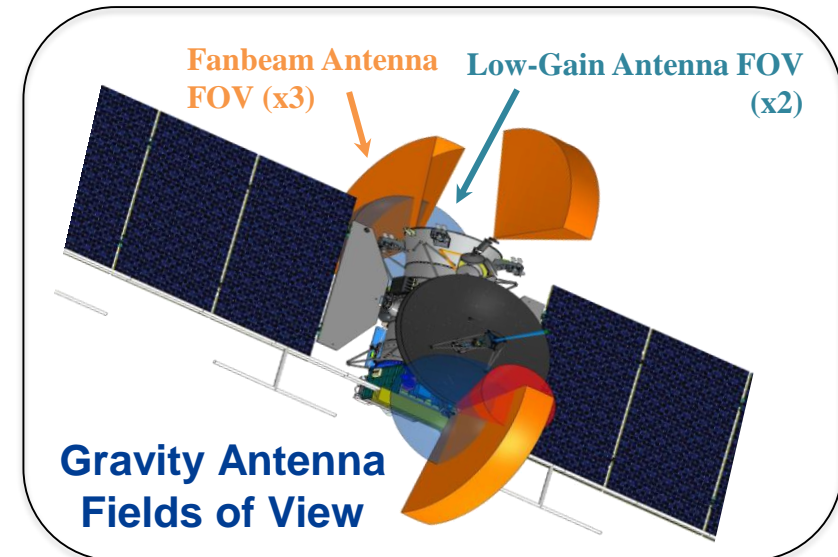




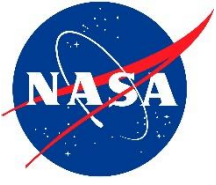
# Europa Clipper Spacecraft Configuration



- Flight system enables observations from all instruments simultaneously
  - Nadir-pointed, ram-pointed, and (typically) gravity science
  - Maximizing science return and facilitating in-depth interdisciplinary scientific interpretation

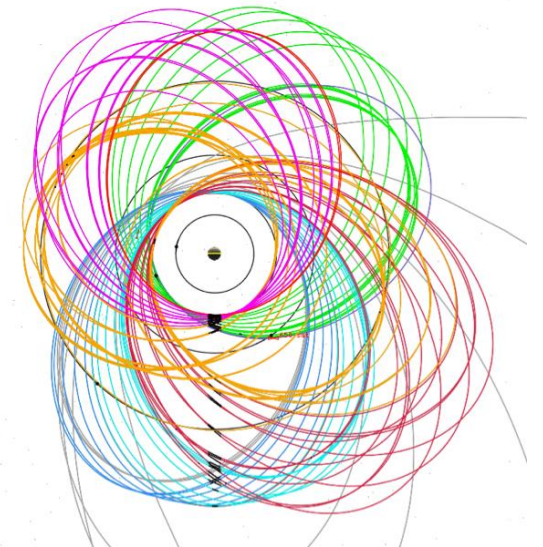
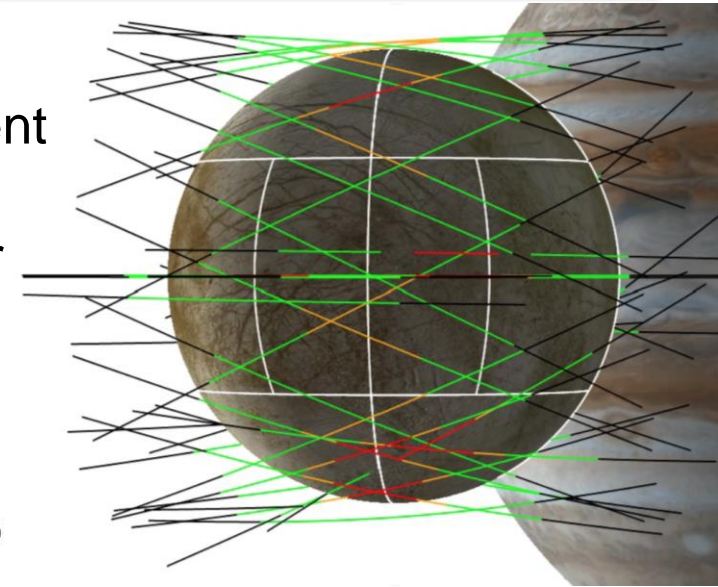
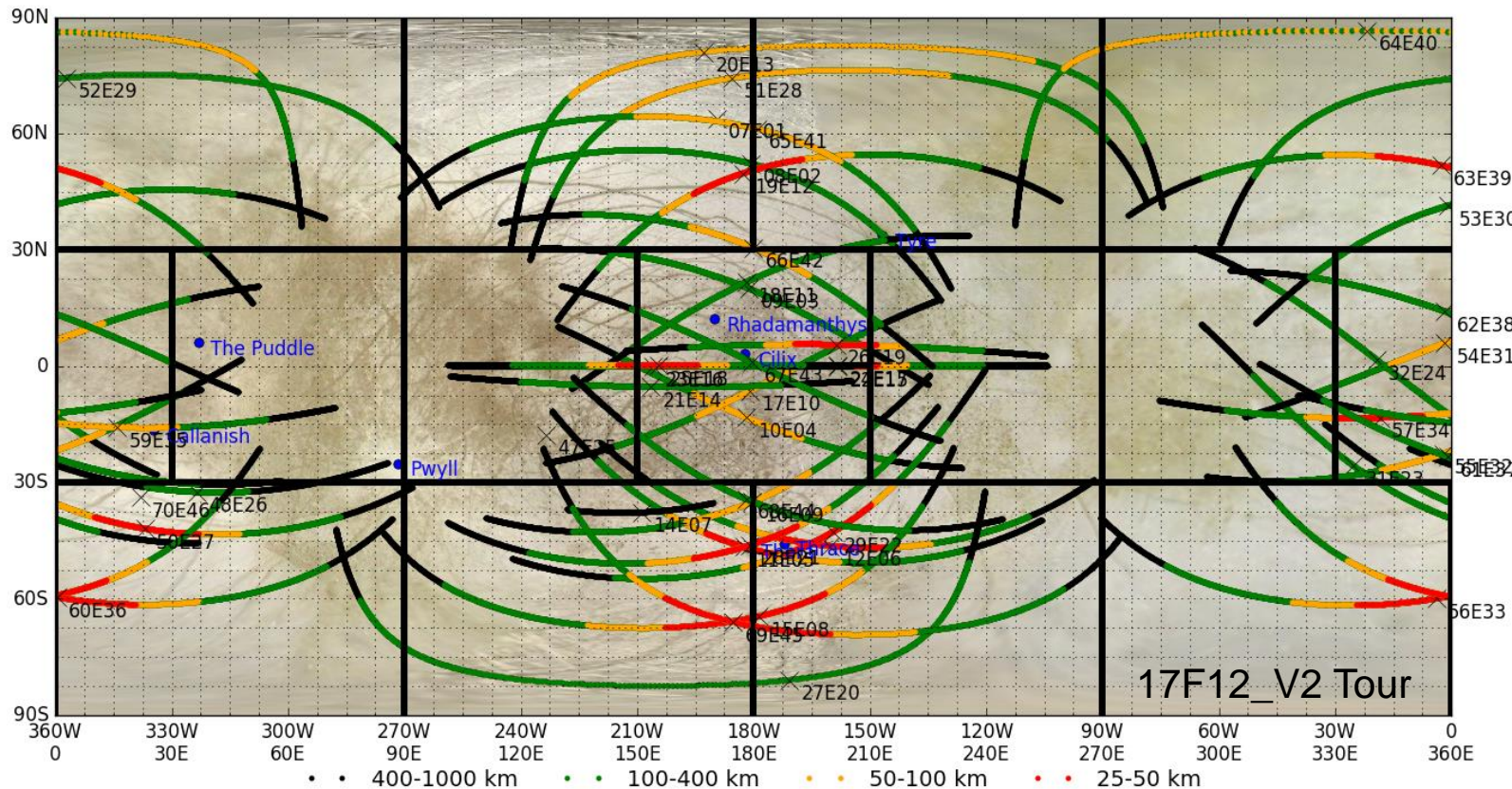






# Europa Clipper Science Approach and Challenges

- Enable global coverage of regions of Europa from Jupiter orbit
- Acquire high-quality data despite the intense Europa radiation environment
- Ensure capability for obtaining synergistic data from all instruments simultaneously and during each flyby, in a simple and repeatable manner

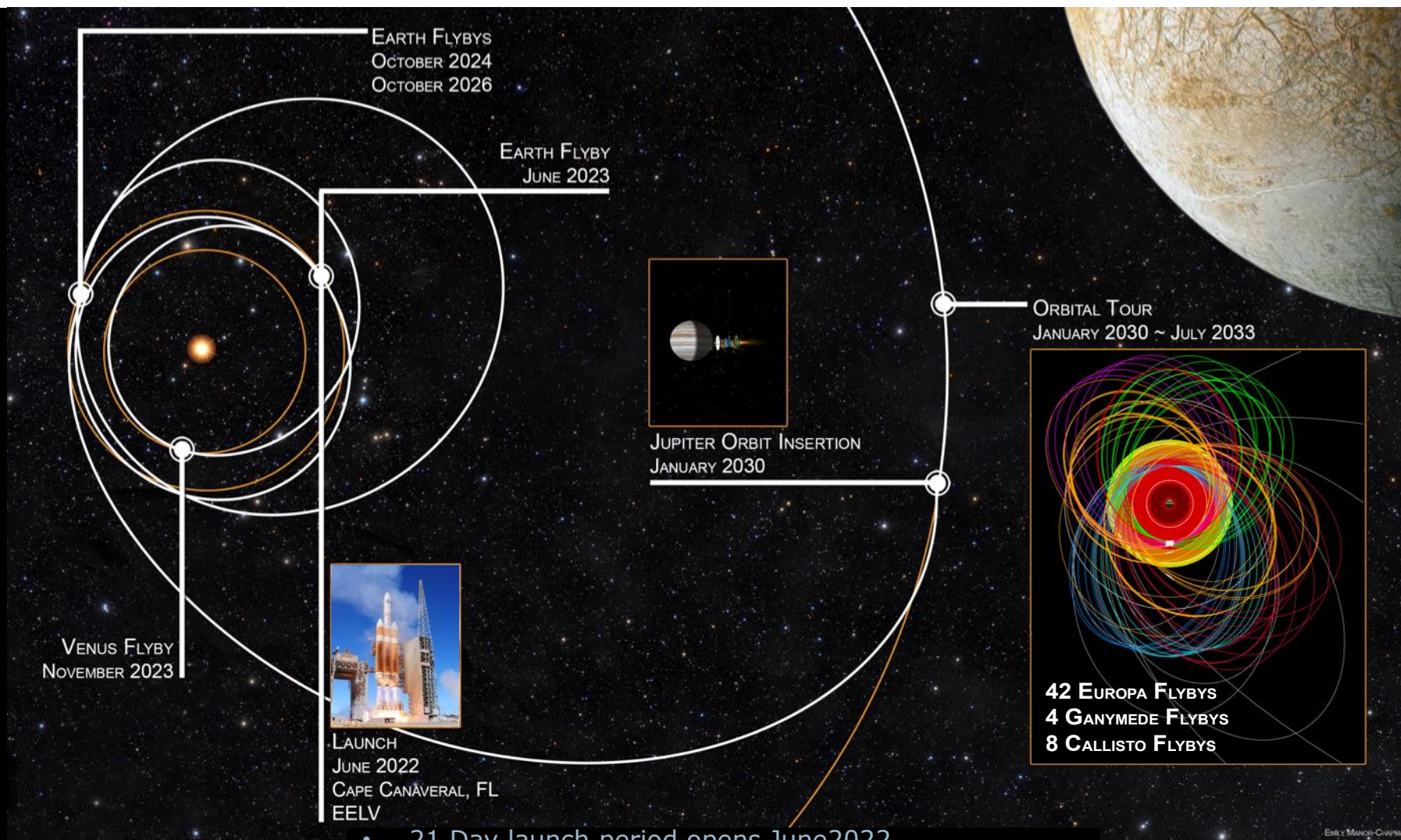




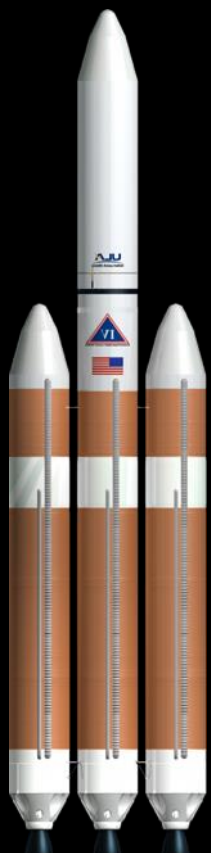


# EVEEGA Interplanetary Trajectory

## EELV Launch Option– (Delta-IV Heavy, Falcon Heavy)



- 21 Day launch period opens June 2022
- Earth/Venus/Earth/Earth Gravity Assist
- Arrive Jovian System January, 2030 (7.5 Years)





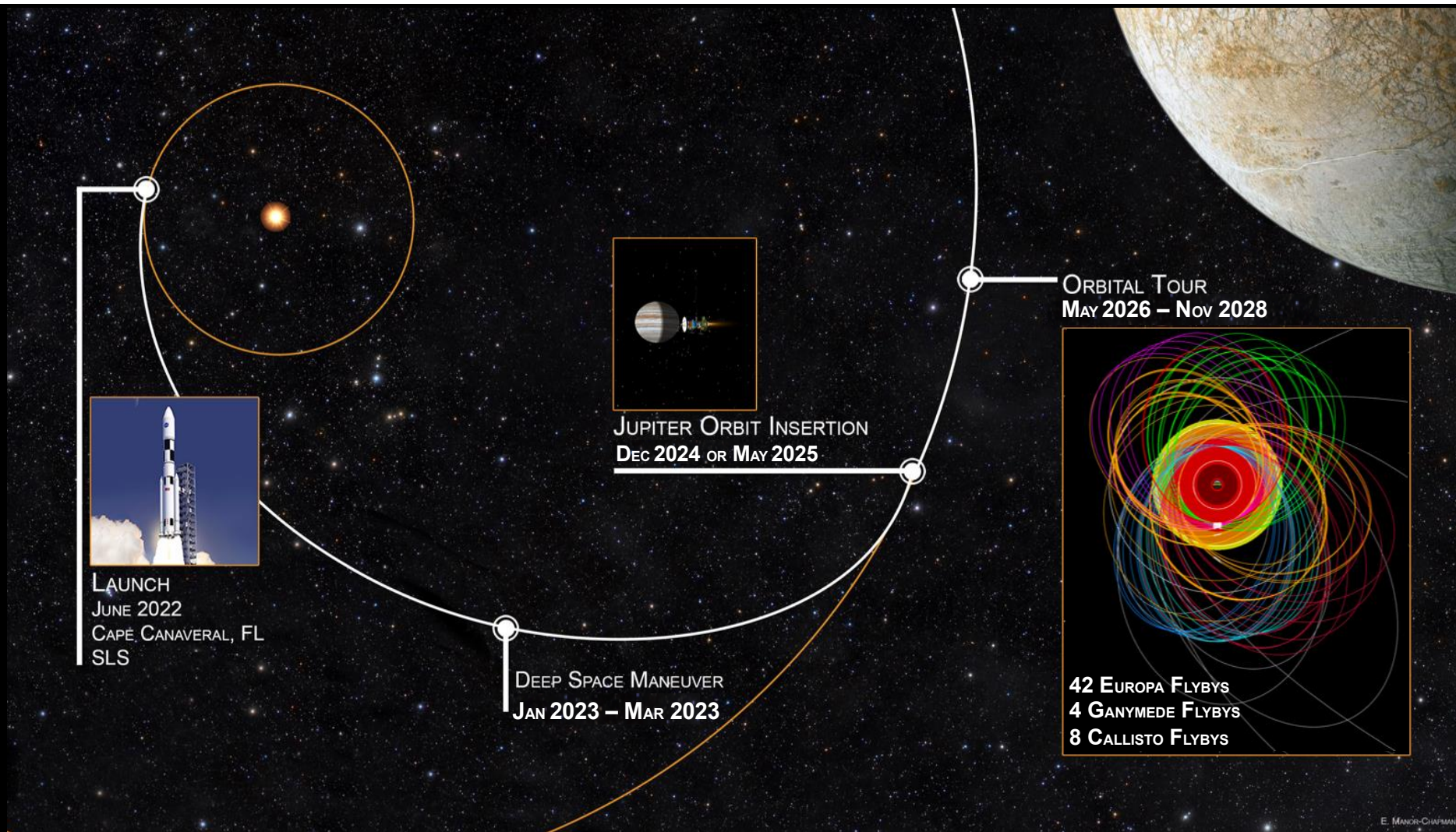


# Direct to Jupiter Trajectory

## SLS Launch Option

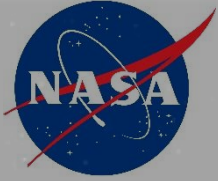


SLS Block 1B



- 21 Day launch period opens June 2022
- Arrive Jovian System March, 2025 (2.7 Years)





# Europa Clipper Science Team

PIs, Co-Is, Project Science (Currently 118 total)

Oleg Abramov  
Amy Barr Mlinar  
**Jordana Blacksberg**  
Diana Blaney  
Don Blankenship  
Scott Bolton  
Christelle Briois  
Tim Brockwell  
**Shawn Brooks**  
Lorenzo Bruzzone  
Bruce Campbell  
Lynn Carter  
Tony Case  
Phil Christensen  
Roger Clark  
**Corey Cochran**  
Geoff Collins  
**Kate Craft**  
Brad Dalton  
**Ingrid Daubar**  
Ashley Davies  
**Serina Diniega**  
Charles Elachi  
**Carolyn Ernst**

Paul Feldman  
Leigh Fletcher  
Yonggyu Gim  
Randy Gladstone  
Thomas Greathouse  
Robert Green  
Cyril Grima  
Eberhard Gruen  
Murthy Gudipati  
Kevin Hand  
Candy Hansen  
Alex Hayes  
Paul Hayne  
Matt Hedman  
Alain Herique  
Karl Hibbitts  
Mihaly Horanyi  
Howett, Carly  
Terry Hurford  
Hauke Hussmann  
Xianzhe Jia  
Steven Joy  
Justin Kasper  
**Sascha Kempf**

Krishan Khurana  
Randy Kirk  
Margaret Kivelson  
**Rachel Klima**  
Wlodek Kofman  
**Haje Korth**  
William Kurth  
Yves Langevin  
Jonathan Lunine  
Marco Mastrogiuseppe  
Tom McCord  
Alfred McEwen  
Melissa McGrath  
Bill McKinnon  
Ralph McNutt  
Mike Mellon  
Jeff Moore  
Olivier Mouis  
Alina Moussessian  
Scott Murchie  
Neil Murphy  
Francis Nimmo  
**Bob Pappalardo**  
Chris Paranicas

Wes Patterson  
Carol Paty  
**Cynthia Phillips**  
Sylvain Piqueux  
Jeff Plaut  
Dirk Plettemeier  
Frank Postberg  
Louise Prockter  
Lynnae Quick  
Julie Rathbun  
**Trina Ray**  
**Carol Raymond**  
**Kurt Retherford**  
**James Roberts**  
Lorenz Roth  
Chris Russell  
Abigail Rymer  
Joachim Saur  
Juergen Schmidt  
**Britney Schmidt**  
Dustin Schroeder  
Frank Seelos  
**Dave Senske**

Mark Sephton  
Everett Shock  
James Slavin  
Todd Smith  
Jason Soderblom  
Krista Soderlund  
John Spencer  
Ralf Srama  
Andrew Steffl  
Alan Stern  
Michael Stevens  
Robert Strangeway  
Ben Teolis  
Nick Thomas  
Gabriel Tobie  
**Zibi Turtle**  
**Steve Vance**  
**Hunter Waite**  
Ben Weiss  
**Joe Westlake**  
Danielle Wyrick  
Duncan Young  
Mikhail Zolotov



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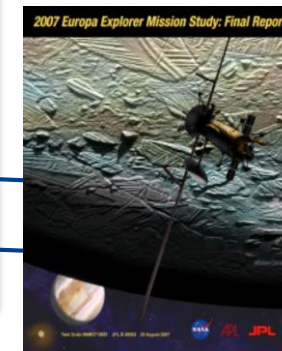
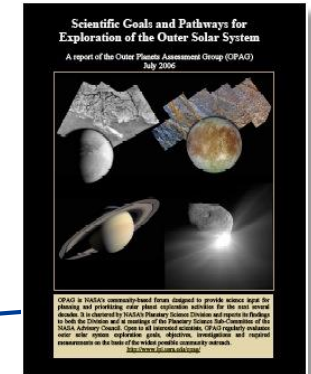
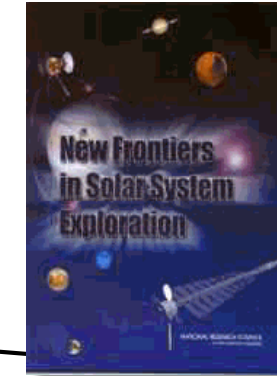
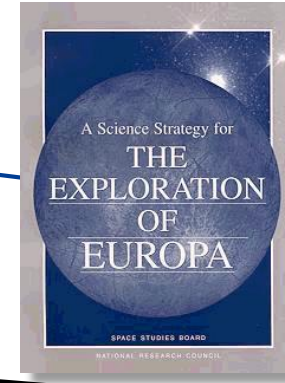
# Backup





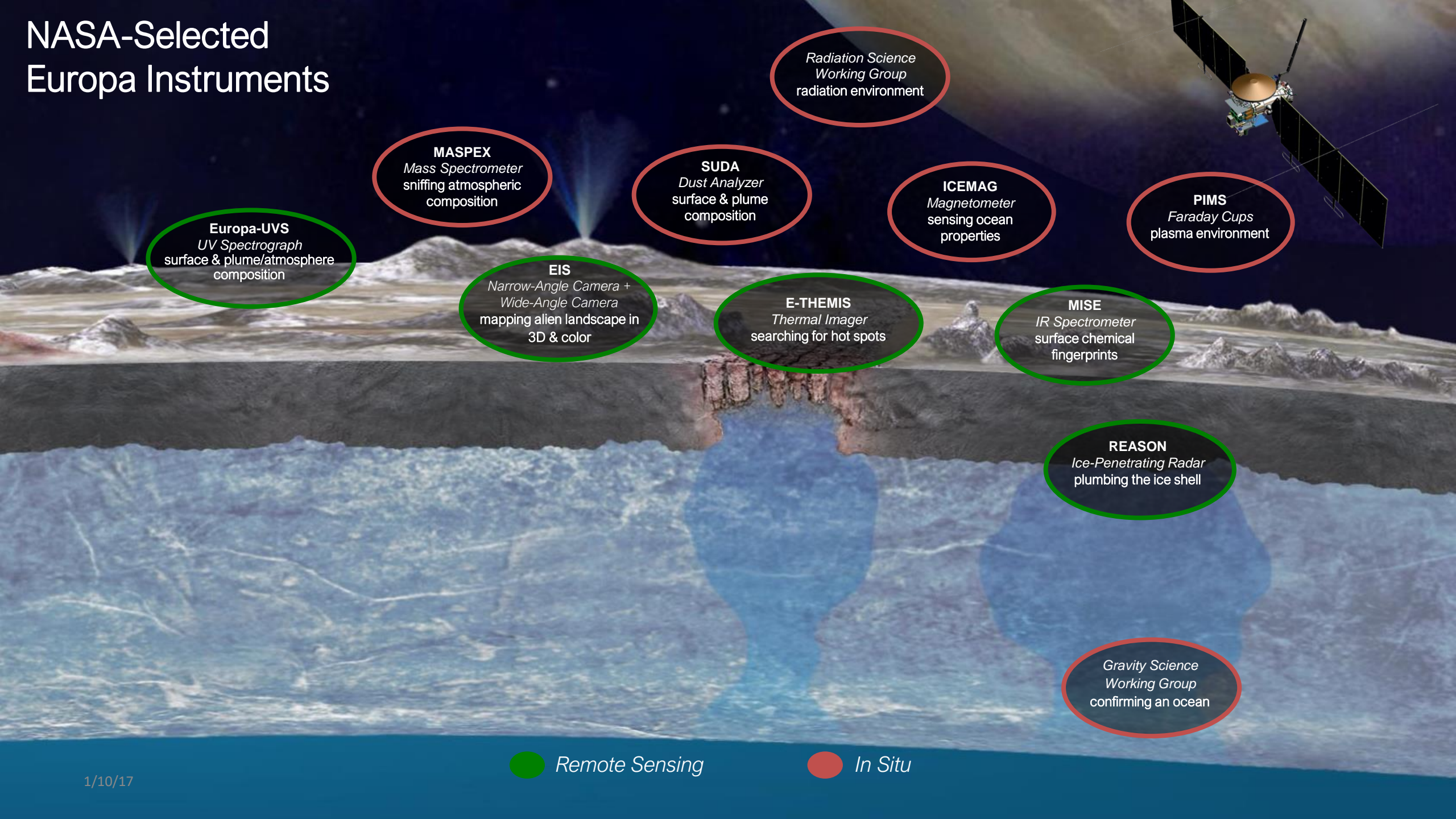
# Timeline of Europa Mission Science Definition

- Europa Orbiter Science Definition Team (1999)
- A Science Strategy for the Exploration of Europa, COMPLEX, National Research Council (1999)
- NASA Campaign Science Working Group on Prebiotic Chemistry in the Solar System (1999)
- New Frontiers in Solar System Exploration, Decadal Survey, (2003)
- Jupiter Icy Moons Orbiter (JIMO) Science Definition Team (2004)
- Scientific Goals and Pathways for Exploration of the Outer Solar System, OPAG (2006)
- NASA Solar System Exploration Roadmap (2006)
- Europa Explorer (EE) Report (2007)
- Jupiter Europa Orbiter Mission Final Report (2008)
- Europa Study Report (2012)

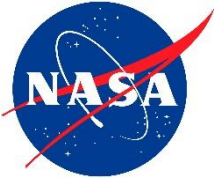


*The Europa science objectives, which have fed into the Level 1s, have a long history of evolution and refinement, thus are well vetted*

# NASA-Selected Europa Instruments

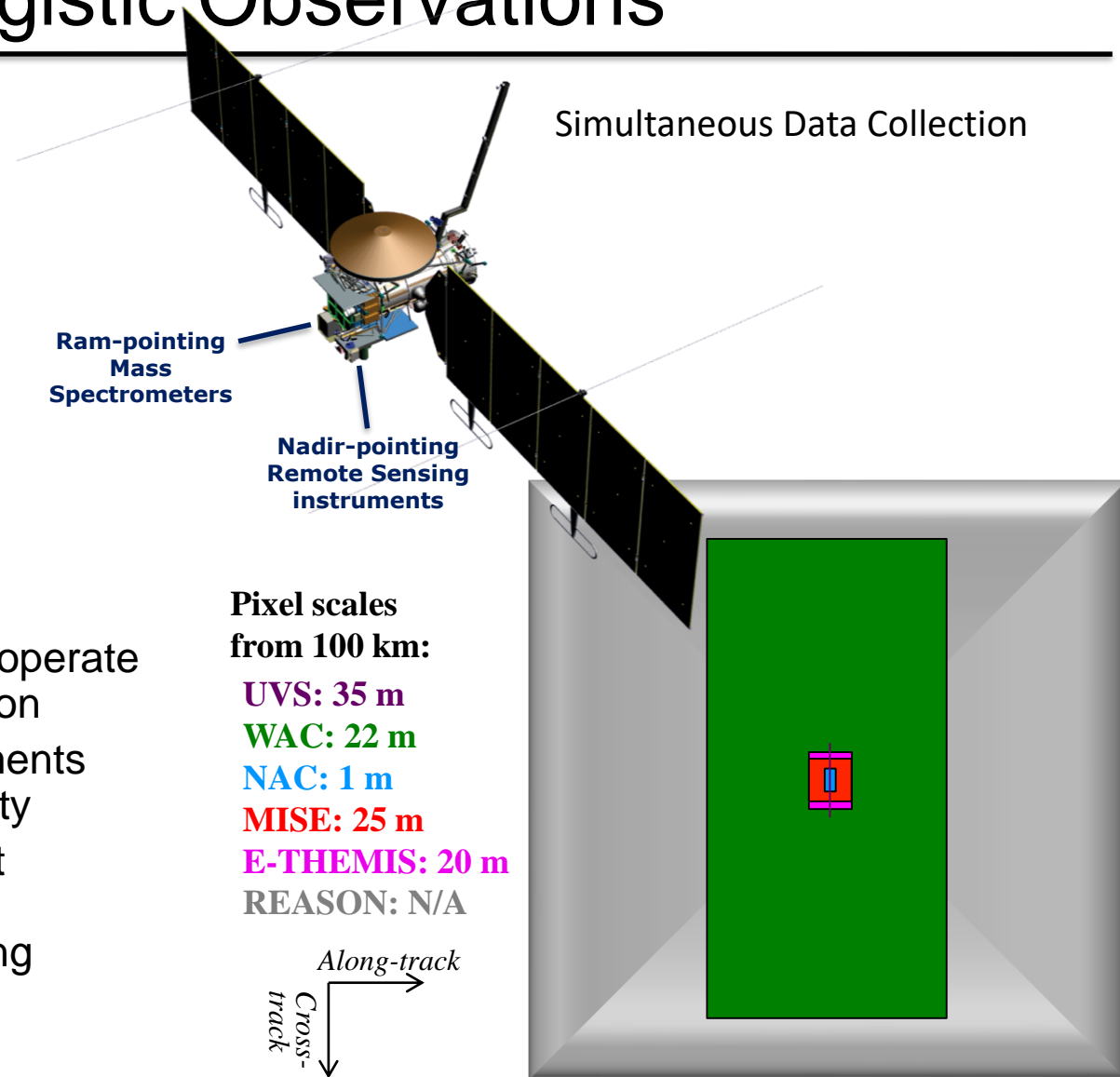


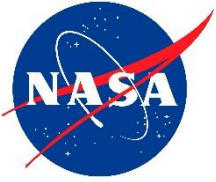




# Nadir-Pointed Flyby Operations: Simultaneous Synergistic Observations

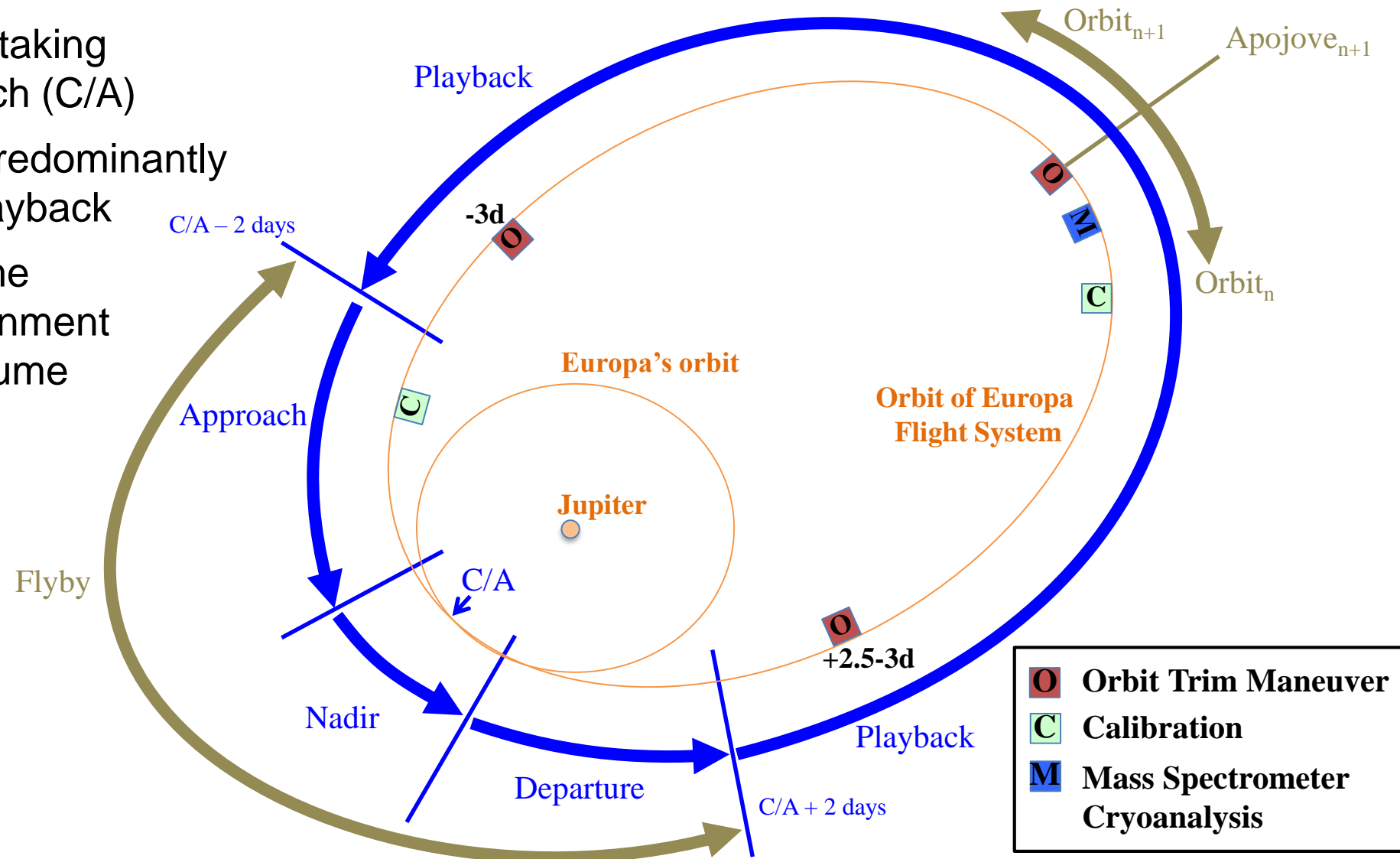
- Flight system enables observations from all instruments simultaneously
  - Nadir-pointed, ram-pointed, and (typically) gravity science
  - Maximizing science return and facilitating in-depth interdisciplinary scientific interpretation
- Synergistic along-track data-taking by remote sensing instruments
  - Co-aligned FOVs
  - During nadir phase, all remote sensing instruments operate in pushbroom fashion, utilizing S/C along-track motion
  - During approach and departure phases, key instruments (EIS-NAC, MISE) can use internal targeting capability
  - During approach and departure, instruments without internal scanning mechanisms (Europa-UVS, E-THEMIS) can utilize S/C motion for global scanning observations, jointly at a common rate





# Europa Clipper Science Orbit Strategy

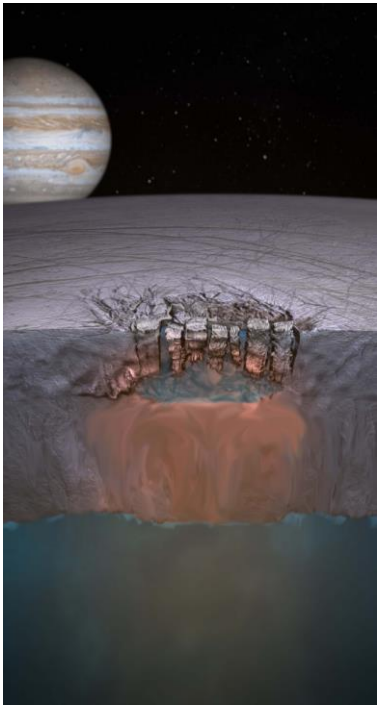
- Intensive science data taking around closest approach (C/A)
- Remainder of orbit is predominantly calibration and data playback
- Flyby strategy limits time in high-radiation environment and optimizes data volume acquired and returned





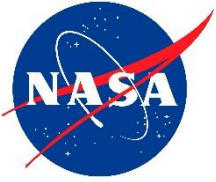


# Europa Clipper Level 1 Science Requirements (1/3)



Ice Shell & Ocean	Mission Success Criteria	Baseline Level 1	Threshold Level 1
	Confirm and constrain the depth to the subsurface ocean, provide information on ocean salinity, and determine processes of surface-ice-ocean exchange.	Map the vertical subsurface structure beneath <b>≥50 globally</b> distributed landforms to ≥3 km depth[, <i>to understand the distribution of subsurface water and processes of surface-ice-ocean exchange</i> ].	Map the vertical subsurface structure beneath <b>≥15 geographically</b> distributed landforms, to ≥3 km depth[, <i>to understand the distribution of subsurface water and processes of surface-ice-ocean exchange</i> ].
		Constrain the <b>average thickness of the ice shell</b> , and the <b>average thickness and salinity of the ocean</b> , each to <b>±50%</b> .	Confirm the <b>presence of a subsurface ocean</b> , and constrain whether the <b>ice shell is in a “thin” (several km) or “thick” (10s km) regime</b> .

Differences between Baseline and Threshold are in **bold**.



# Europa Clipper Level 1 Science Requirements (2/3)



Composition	Mission Success	Baseline Level 1	Threshold Level 1
	Identify the composition and sources of key non-ice constituents on the surface and in the atmosphere, including any carbon-containing compounds.	Create a compositional map at $\leq 10$ km spatial scale, covering $\geq 70\%$ of the surface[, <i>to identify the composition and distribution of surface materials</i> ].	Create a compositional map at $\leq 10$ km spatial scale, covering $\geq 40\%$ of the surface[, <i>to identify the composition and distribution of surface materials</i> ].
		Characterize the composition of <b><math>\geq 50</math> globally distributed</b> landforms, at $\leq 300$ m spatial scale[, <i>to identify non-ice surface constituents including any carbon-containing compounds</i> ].	Characterize the composition of <b><math>\geq 15</math> geographically distributed</b> landforms, at $\leq 25$ km spatial scale[, <i>to identify non-ice surface constituents including any carbon-containing compounds</i> ].
		Characterize the composition and sources of <b>volatiles, particulates, and plasma</b> , with sensitivity sufficient to identify the signatures of non-ice materials including any carbon-containing compounds, in <b>globally distributed</b> regions of the atmosphere and local space environment.	Characterize the composition and sources of <b>volatiles or particulates</b> , with sensitivity sufficient to detect the signatures of non-ice materials including any carbon-containing compounds, in <b>geographically distributed</b> regions of the atmosphere and local space environment.

Differences between Baseline and Threshold are in **bold**.



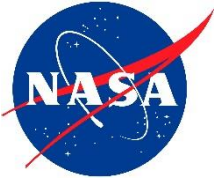


# Europa Clipper Level 1 Science Requirements (3/3)



	Mission Success	Baseline Level 1	Threshold Level 1
Geology	Produce a $\leq 100$ -m spatial-scale map over $\geq 30\%$ of the surface, and determine the three-dimensional characteristics of major landform types at higher resolution.	Produce a controlled photomosaic map of $\geq 80\%$ of the surface at $\leq 100$ -m spatial scale[, <i>to map the global distribution and relationships of geologic landforms</i> ].	Produce a controlled photomosaic map of $\geq 30\%$ of the surface at $\leq 100$ -m spatial scale[, <i>to map the distribution and relationships of geologic landforms</i> ].
		<b>Characterize</b> the surface at $\leq 25$ -m spatial scale, and measure topography at $\leq 15$ -m <b>vertical</b> precision, across $\geq 50$ <b>globally distributed</b> landforms[, <i>to identify their morphology and diversity</i> ].	<b>Image</b> the surface at $\leq 50$ -m spatial scale, and measure topography at $\leq 20$ -m <b>vertical</b> precision, across $\geq 15$ <b>geographically distributed</b> landforms[, <i>to identify their morphology and diversity</i> ].
		Characterize the surface at $\sim 1$ -m scale to determine surface properties, for $\geq 40$ sites each $\geq 2$ km x 4 km.	[N/A]
Current Activity	Search for current activity.	<b>Search for and characterize any</b> current activity, notably plumes <b>and</b> thermal anomalies, <b>in regions that are globally distributed</b> .	<b>Search for</b> current activity, notably plumes <b>or</b> thermal anomalies.

Differences between Baseline and Threshold are in **bold**.



# Europa Clipper Programmatic Level-1 Requirements

## Data Management



	Candidate Level 1
Science Data Archival	The Europa Science Team, led by the Project Scientist, shall be responsible for initial analysis of data, subsequent data delivery to the <u>Planetary Data System (PDS)</u> , the publication of scientific findings, and communication of results to the public.
Calibration Data Archival	The Europa Mission Project Manager shall be responsible for collecting engineering and ancillary information necessary to validate and calibrate the scientific data prior to PDS delivery.
Archival Latency	The Europa Mission Team shall deliver data products to the PDS in usable form within six months from the time of receipt of data and required ancillary information at instrument processing facilities.
Public Data Access	The Europa Mission science data shall be made available to the science community, via the PDS, without restrictions or proprietary data rights of any kind.

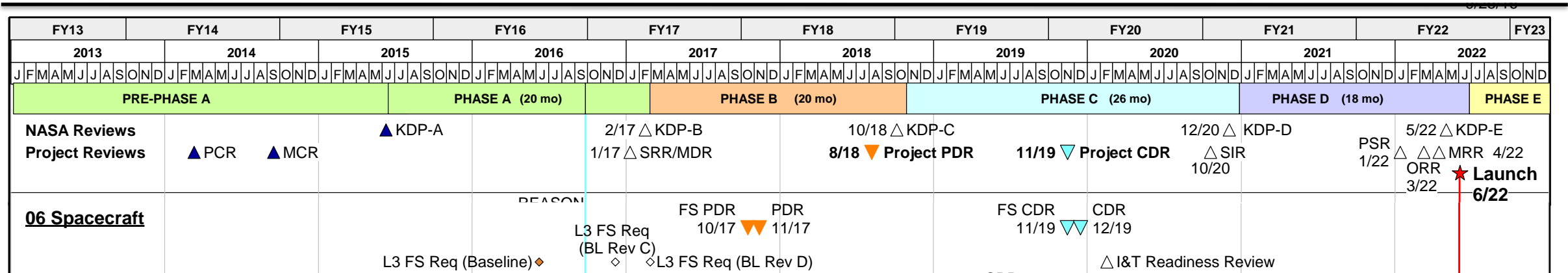
From Solar System Exploration Program: Europa Mission PLRA – November 2016





# Europa Clipper Project-Level Lifecycle Schedule

## Key Project Reviews

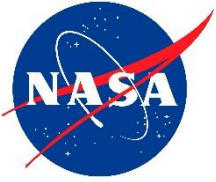


- Propulsion Subsystem PDR 6/27-29/17 (Goddard)
- Propulsion Module PDR 7/24-27/17 (APL)
- Flight System PDR 10/17-20/17 (JPL)
- Europa-UVS PDR 11/16-17/17 (SWRI)
- PIMS PDR 12/6-7/17 (APL)
- EIS PDR 1/9-11/18 (APL)
- SUDA PDR 1/17-18/18 (Univ. Colorado)
- Solar Array Requirements Review 1/22/17 (JPL)
- Power PDR 1/23-24/18 (JPL)
- E-THEMIS PDR 1/30-31/18 (ASU)
- ICEMAG PDR 2/14-15/18 (JPL)
- Guidance, Navigation & Control PDR 2/7-8/18 (JPL)
- Mechanical PDR 2/12-15/18 (JPL)

We  
are  
here

Spacecraft  
Payload  
Mission System  
Project

- Thermal PDR 2/15-16/18 (JPL)
- Radio Frequency Module / Telecom PDR 3/14-15/18 (JPL)
- REASON PDR 3/26-27/18 (JPL)
- Radiation Monitors PDR 4/18 (APL)
- Avionics PDR 4/30-5/4/18 (JPL)
- MISE PDR 4/25-26/18 (JPL)
- MASPEX PDR 5/15-16/18 (SWRI)
- Fault Management PDR 5/15/18 (JPL)
- Mission Design & Navigation PDR 6/4-5/18 (JPL)
- Mission Operations System & Ground Data System PDR 6/6-7/18 (JPL)
- Project PDR 8/20-24/18 (JPL)



# Europa Clipper Mission Science Organization

